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MEASURING THE SHIELDING EFFICIENCY OF SCREENED ENCLOSURES

NAVAL RESEARCH LABORATORY

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MEASURING THE SHIELDING EFFICIENCY OF SCREENED ENCLOSURES

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ABSTRACT

A review has been made of shielded-enclosure methods employed to prevent interference or interaction between various types of electronic equipment.

Studies of methods of measuring attenuation revealed the "door-open, door-closed" and "inside, outside" methods as having many disadvantages. A more reliable method employs a transmitter-loop assembly located outside and away from any large object which might reflect radio waves. After taking a series of field intensity measurements at various distances and angles from the assembly, the room was constructed around the transmitter-loop and measurements were taken at the same locations as before.

The uniform-field method was chosen for reference purposes in this investigation because it was considered to be fundamentally sound and capable of rendering consistent results. Each room was, in turn, mounted on a flat-bed truck and transported to the sites of various high-power transmitting stations where suitable conditions might be found. Although there is possibility of disagreement over how the attenuations should be defined and measured, this method has the advantage of repeatability. However, it has the serious disadvantages of being very costly, time-consuming, and limited to rather small portable-type rooms, and is, therefore, not recommended for general use.

Differences in shielding efficiency between a double-shielded room and a cell-type room are tabulated. A room without soldered seams and protected from the weather by a plywood roof and waterproof canvas sides showed some reduction of shielding effectiveness after remaining outside for a year. After tightening all loose bolts, the attenuation was almost the same as at the beginning of the year

A transfer-impedance method of evaluating shielded enclosures has been evolved at this Laboratory. Although the results are not directly obtainable in decibels of attenuation, and, like all other methods, it is not readily adaptable to vhf and higher frequencies, it does have the following advantages: relatively low-power oscillators can be used in place of more powerful transmitter-antenna combinations; the sensitivity is adequate for evaluating well-shielded rooms; measurements are easily standardized and specified; and there are no interfering signals produced at distances remote from the room.

PROBLEM STATUS

This is a final report on the problem; unless otherwise notified by the Bureau, the Laboratory will close the problem one month from the mailing date of this report.

AUTHORIZATION

NRL Problem R07-39T
NA 120-826

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MEASURING THE SHIELDING EFFICIENCY OF SCREENED ENCLOSURES

INTRODUCTION

The increasing use of electronic equipment in recent years, together with a general increase in transmitting powers, has considerably multiplied the difficulty of preventing interference or interaction between various types of equipment. Not only in laboratories but also in work and operational areas, one of the steps frequently taken to minimize trouble from radio interference sources is to employ a shielded enclosure in which is placed either the equipment being interfered with, or the equipment producing the interference.

Methods for evaluating the shielding efficiency of such enclosures have, in general, been unsatisfactory. A simple and reliable method that can be used for specification and comparison purposes is needed by the armed services and by industry in general.

In order to study the problem as objectively as possible, a project was established at the Naval Research Laboratory to review the methods in use and develop, if possible, a method that would lend itself to general application by the material Bureaus of the Navy Department.

The initial procedure toward accomplishing the objectives of this problem was to make measurements on two types of shielded rooms, under conditions that were considered to be as representative as possible of the fundamental concept of the attenuation obtained from shielded enclosures. Although there is possibility of disagreement over how the attenuation should be defined and measured, a uniform-field method was considered to have numerous advantages, the principal one being repeatability. The results obtained were to serve as reference for subsequent investigations. It had the serious disadvantages of being very costly and time-consuming.

A transfer-impedance method, with a completely different approach, appears to have promise of being suitable for general application as a standardized test procedure. This method is particularly applicable for acceptance tests on shielded rooms constructed under contract to the Services.

SHIELDING THEORY

Only a few brief statements of shielding theory as applicable to screened room study will be given here. A more complete discussion of the basic theory is available in other reports (1-5).

When an electromagnetic wave traveling through space impinges upon a sheet of conducting material, a certain reflection of energy occurs due to the abrupt change in the

impedance of the medium. In passing through the conducting sheet, a further loss of energy occurs, and at the opposite surface, a second reflection of energy takes place which still further attenuates the energy. Thus, the total attenuation experienced by the wave in passing through the conducting sheet may be divided into two components: a reflection loss which is the total of the reflection losses at each surface, and a penetration loss which is proportional to the thickness of the material. Where two or more shields are used, additional reflection and penetration losses occur.

By applying the above principles and the appropriate formulas, the shielding effectiveness of an enclosure constructed of homogeneous material without seams or other discontinuities may be calculated to close approximation for a given incident field. For nonhomogeneous materials, such as copper screen and hardware cloth, the losses can be calculated only with considerable difficulty (6). This is also true for homogeneous materials whenever doors or ventilation openings are present, which is necessarily the case for practical rooms.

MEASUREMENT OF ATTENUATION

Before reviewing some of the methods that have been used and advocated for evaluating shielded room effectiveness, it should be noted that the effectiveness of a room at a given frequency is not a unique quantity, but depends upon: the nature of the incident wave, i.e., the relative value of E and H, the polarization with respect to the discontinuities in the shielding, and the shape of the wave front; the kind of pickup device used to detect the leakage, i.e., its size and form, and whether it responds to magnetic or electric fields; the placement of the pickup device with respect to the room; and the physical size and relationship of discontinuities in the shielding with respect to the dimensions of the room.

Measurements made by using a field produced by a source either within or immediately outside the room are subject to the above variables, and also to the fact that all parts of the room are not subjected to the same field intensity and polarization. In practice, additional complications almost always arise because of the confined quarters in which most screened rooms are located.

A common method in use that might be called the "door-open, door-closed" method is subject to the above criticisms. This method consists of placing a transmitter of moderate power outside of the room, rather close to and directly opposite the door. With the door open, a measurement of the field intensity is taken at the center of the room. The door is then closed and another measurement taken at the same location. The ratio of the two readings, expressed in decibels, is taken as the attenuation of the room. A variation of this method is to reverse the positions of the transmitter and the field intensity meter. An advantage of the latter method is that the possibility of transmitter radiation interfering with other services is greatly lessened. The former method had the advantage that field intensity meter was less subject to interference from extraneous sources.

The "inside, outside" method is similar to the previous method in that a transmitter is used to set up an electromagnetic field (probably having a high gradient) around the room. The intensity of this field is measured with a suitable field intensity meter, by placing the pickup device as close to the outside surface of the room as possible, without seriously impairing the operation of the pickup device as a result of the stray capacitance between the device and the surface of the room. The field at the center of the room is then measured with the door closed and the ratio of the two readings, expressed in decibels, is taken as the attenuation of the room. This method also has the serious disadvantage of being limited to transmissions on assigned frequencies.

One of the main difficulties with the two methods discussed so far is that the power of the transmitters usually available for such tests is not great enough to allow the radiating antenna to be placed at a sufficient distance from the room under test to insure a reasonably

small gradient around the room. The limiting factor is the sensitivity of the field intensity meter used for making the measurements inside the room. For example, assuming a sensitivity of 20 microvolts per meter and a room having an attenuation of 120 decibels, an external field of 20 volts per meter would be required to make the measurement. To produce a field of this intensity having a small gradient over a space equivalent to that occupied by the room would require a high-power transmitter and an efficient antenna system. If a very wide range of frequencies are to be used the problem is further complicated.

A slightly different approach was described in (7). A transmitter with a power of about 500 watts connected to a balanced loop antenna was placed in an outside location, away from any large objects which might reflect radio waves. A series of field intensity measurements were then made at various distances and angles from the transmitting loop. The room to be measured was then constructed around the transmitter-loop assembly and measurements of the field intensity again taken at the same locations as before. Although the reliability of the results obtained with this method is probably better than with any of the others described so far, it is still subject to most of the disadvantages already mentioned, particularly that of unlicensed transmissions.

UNIFORM-FIELD METHOD OF EVALUATING SHIELDED ENCLOSURES

The uniform-field method, while not recommended for general use because of the cost, and because it is limited to rather small portable-type rooms, was chosen for reference purposes in this investigation because it was considered to be fundamentally sound and capable of rendering consistent results.

In order to measure the attenuation of the rooms under investigation in radio frequency fields as uniform as possible, each room was, in turn, mounted on a flat-bed truck and transported to the sites of various high-power transmitting stations where suitable conditions might be found. The various commercial and government radio station sites chosen for these tests are given in Table 1.

TABLE 1
Transmitter Sites Used for the Uniform-Field Attenuation Measurements

Frequency*	Call	Location	Nominal Power (kw)
18 kc	NSS	Annapolis, Md.	300
88 kc	NSS	Annapolis, Md.	50
122 kc	NSS	Annapolis, Md.	50
630 kc	WMAL	Bethesda, Md.	5
1.5 Mc	WTOP	Wheaton, Md.	50
5.0 Mc	WWV	Beltsville, Md.	10
15 Mc	WWV	Beltsville, Md.	10
78 Mc	WTTG	Arlington, Va.	20

* In addition, transmitters were available operating on frequencies of 217, 672, 1300, 2800, and 3400 megacycles.

Procedure for Measuring Attenuation up to 78 Mc

The room, mounted on a truck, was taken to a location rather close to the antenna system of the transmitter being used. A quick check of the magnitude of the field inside the room was then made so that the truck could be repositioned as far away from the antenna system of the transmitter as possible, the governing factor being that the field intensity inside the

room must not fall below the sensitivity of the measuring equipment. After choosing a suitable location, the field intensity was carefully measured at the center of the room. The pickup device was then moved along the walls of the room, paying particular attention to discontinuities in the shielding, such as door seals, ventilation openings, and joints; and field intensity readings were taken of any appreciable sources of leakage into the room. The readings obtained at points other than the center of the room were considered as supplemental data, since the center of the room was the main point of reference.

The room was then moved far enough away from this site so that it did not distort the field and a measurement was made of the external field existing at the same location that the room formerly occupied. The pickup device was next moved around an area equal to that formerly occupied by the room to insure that the condition of negligible gradient over the dimensions of the room had been satisfied. The attenuation was then computed by the usual equation.

$$db = 20 \log \frac{\text{(field intensity in the open)}}{\text{(field intensity in the room)}}.$$

To cover the range of frequencies from 18 kilocycles to 78 megacycles the following measuring equipments were used: Radio Test Set AN/URM-6 (Stoddart Model NM-10A); Field Intensity Meter, RCA Model 308-A; and the Noise-Field Intensity Meter TS-587A/U (Stoddart Model NMA-5).

Procedure for Measuring Attenuation above 78 Mc

For frequencies 217 megacycles and above, Receiving Equipment AN/APR-4 was used in conjunction with an oscilloscope, and a mutual-inductance attenuator. A somewhat different measuring technique was necessary on these higher frequencies. The room was placed in front of a transmitter (Figure 1a) at a distance close enough to permit a measurable signal to be received inside the room. The antenna used inside the room was a simple half-wave antenna connected by coaxial cable to the AN/APR-4 receiver. The video output of the receiver was applied to the vertical plates of an oscilloscope.

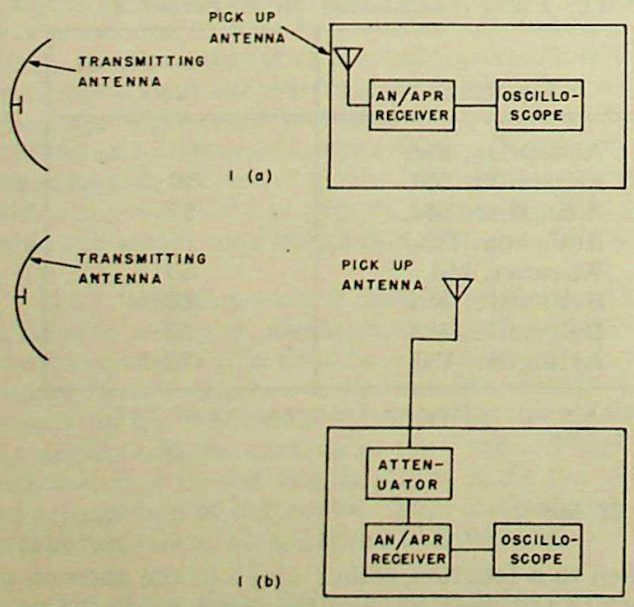

Figure 1 - Measuring technique used above 200 megacycles

The procedure for the actual measurement was as follows: first, the receiver, in the room, was tuned to the signal, with the room door open slightly, if necessary. The door was then closed tightly, the pickup antenna moved to various locations in the room, and the height of the pattern on the scope and the corresponding settings of the intermediate-frequency attenuator on the AN/APR-4 receiver were noted. The latter settings were as high as could conveniently be made to avoid the possibility of overloading the intermediate frequency stages of the receiver.

The room was then moved out of the strong field of the beamed transmissions (Figure 1b) and the antenna used inside the room was placed in the center of the space formerly occupied by the room. A 125-foot length of Radio Frequency Cable RG-5/U was then connected to the pickup antenna and lead back to the room, where it was brought

inside through a specially-made adapter. The reason for keeping the receiver inside the room was to avoid the leakage through the case of the receiver, which existed in strong fields. A mutual-inductance attenuator, inserted ahead of the input to the receiver, was adjusted until the same signal level was observed on the screen of the oscilloscope as before. The i-f attenuator of the receiver was maintained at the same setting as before. The attenuation of the room, measured in this manner, was then equal to the insertion loss of the mutual-inductance attenuator plus the loss in the 125-foot length of RG-5/U cable. The latter values were measured in the laboratory for each frequency used.

SHIELDED-ROOM CONSTRUCTION

The types of rooms most commonly used as shielded enclosures may be divided into three catagories, namely: single-shielded, double-shielded, and cell-type. The single-shielded room consists of one layer of conducting material completely surrounding the enclosed space (8). The electrical connections entering the room are isolated by a set of radio-frequency filters mounted on either the inner or outer surface of the shield. A double-shielded room has two layers of conducting material completely surrounding the enclosed space. The layers are usually separated from one to six inches, depending on the method of construction. The two shields are usually connected together electrically at one point only in order to avoid circulating currents flowing between the shields. This connection is made at the same point that the power leads are brought into the room. Sometimes two sets of power-line filters are used for double rooms—one mounted on the outer surface and the other on the inner surface. If it is desired to have the inner shield "floating," the filter is placed between the shields. The cell-type room has two metallic layers. However, walls are constructed of panels, each panel being a "cell" or completely enclosed unit. In other words, the room is doubly shielded with continuous connection between the two shields around each unit or section. The attenuation of this type room should lie between that of a single shield and that of a double shield of conventional construction (7).

The first room tested during this investigation was designed and built at the Naval Research Laboratory. It was constructed of standardized, double-shielded sections so designed that rooms of various sizes can be formed by adding additional standard sections. Figures 2 and 3 show a room in various stages of assembly, and Figure 4 shows a completed room of this type. The conducting layers were of "Sisalcraft" and attached to 3/8-inch plywood spaced by 2-inch by 4-inch lumber. Sisalcraft is the trade name of a material used in building construction as a moisture barrier, and consists of a thin layer of copper (about 3 mil) backed on one side by a bituminous material, followed by a layer of coarse paper. Each seam, that is, the two edges around each section was overlaid with a strip of sheet copper, about three inches wide, which was soldered to the adjoining copper along each edge. Every joint in both the inner and outer layers was continuously soldered. Double metallic weatherstripping was used around the door. The two layers were electrically connected only at the point where the power leads were brought into the room through metal conduit. Two sets of Tobe Deutschmann 1180 screen room filters mounted in standard boxes were used, one inside and the other outside the enclosure. The openings for light and ventilation were covered with 1/4-inch hardware cloth which had been dipped in a copper-plating solution. The inner and outer sections of the hardware cloth were continuously soldered to the Sisalcraft. Figure 5 shows the inner filter box and a portion of the light wells.

The cell-type room used in this investigation was made available by the ACE Engineering and Machine Company, Inc., Philadelphia, Pa. The room was composed of sections consisting of a wood framework around which specially designed 22-mesh copper screening was tightly stretched. It was woven with annealed copper wire in one direction and hard-drawn copper wire in the cross direction. The sections were bolted together tightly, with electrical contact being made between the sections at each edge. Pressure plates were used under each bolt to maintain compression along the edges of adjoining sections. Pressure alone was used to keep the sections in electrical contact with each other. The door of the room

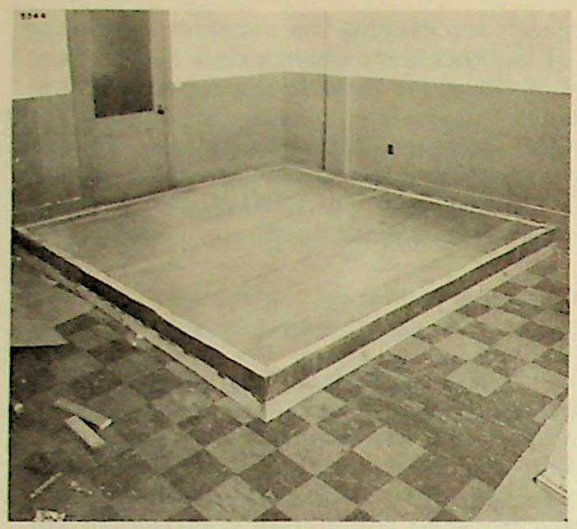

Figure 2 - Assembled floor of a double-shielded room

Figure 3 - Workman assembling wall panels of a double-shielded room

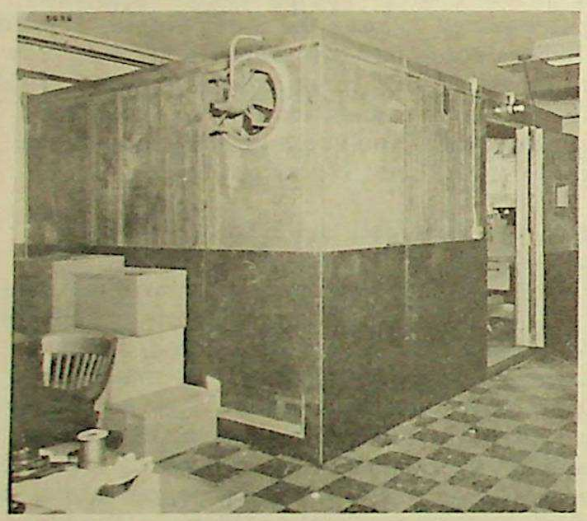

Figure 4 - A completed double-shielded room

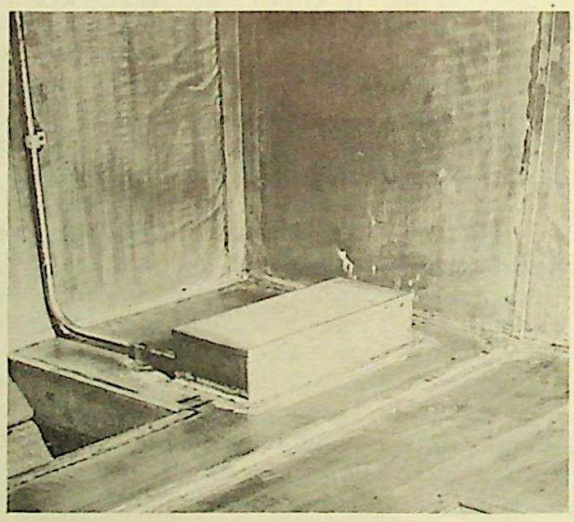

Figure 5 - Inner filter box as installed on the double-shielded room

closed against two sets of serrated Phosphor-bronze strips (Figure 6), which normally ensured good contact. The power line was brought into the room through a set of externally mounted filters. Figure 7 shows an assembled ACE room and Figure 8 shows the room, with a weather covering, mounted on the truck for making the uniform-field measurements of attenuation. Additional design data on this kind of room is given in (9).

MEASURED RESULTS FOR THE TWO ROOMS

Curves of attenuation (as measured at the center of the room) versus frequency are plotted in Figure 9 for the double-shielded and cell-type rooms. The general shapes of the curves are similar, showing a steady rise in attenuation from 18 kilocycles up to about

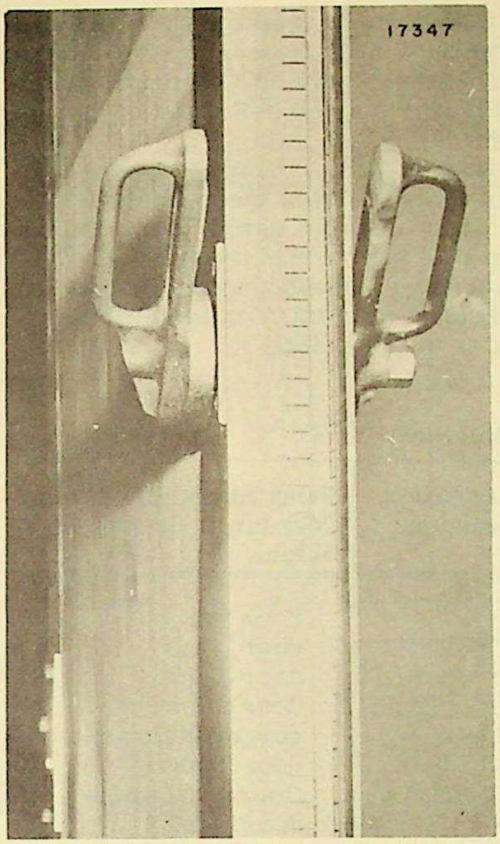

Figure 6 - Contact strip used on door of ACE cell-type room

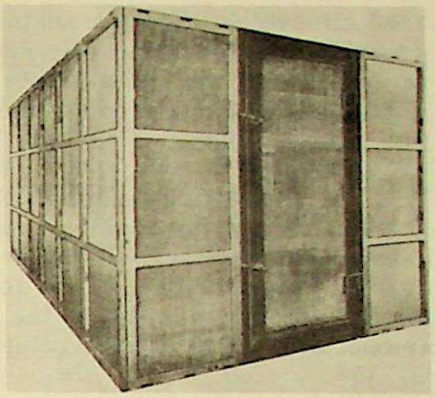

Figure 7 - View of assembled ACE cell-type room

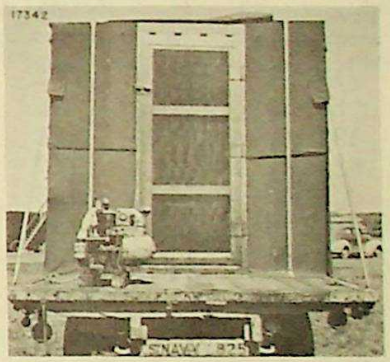

Figure 8 - ACE cell-type room mounted on truck for field tests

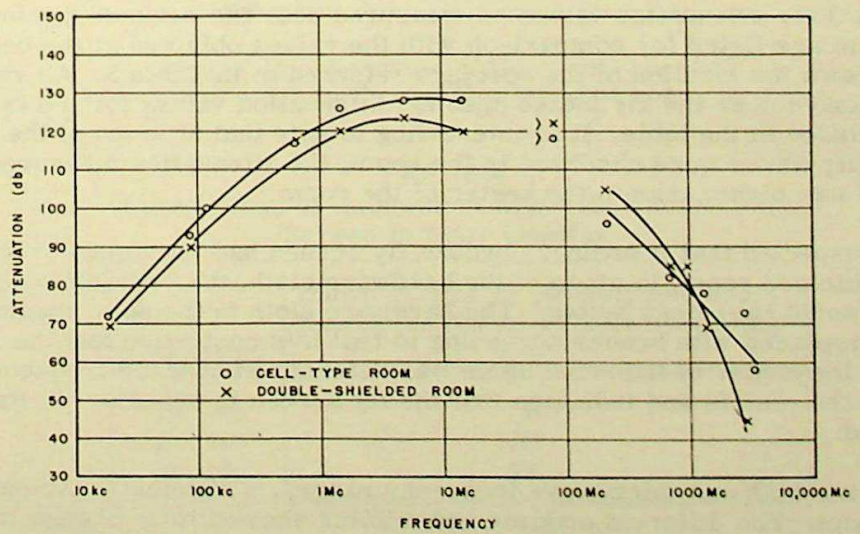

Figure 9 - A comparison of the attenuation curves for the double-shielded and cell-type rooms

1500 kilocycles. The attenuation then levels off with increasing frequency until the region of probable room resonance is reached, somewhere between 50 and 100 megacycles. Because of the unavailability of suitable strong fields in this frequency range, it was found impossible to make attenuation measurements, although at 78 megacycles some indication of the magnitude was obtained.

The values of attenuation plotted in Figure 9 were all taken from measurements made at the center of the room. It was possible, at nearly all frequencies used, to find locations near the walls or doors of the rooms where a considerable increase in the field strength over that measured in the center of the room was observed. Table 2 shows a comparison, for the ACE room, between the attenuation values measured near the location of the greatest amount of leakage and the values measured at the center of the room.

TABLE 2
Measured Attenuation of ACE Shielded Room

Frequency	Attenuation to Center of Room (db)	Attenuation to Location of Maximum Leakage (db)	Location of Maximum Measured Leakage into Room
18 kc	72	41	door jamb
88 kc	93	59	door jamb
122 kc	100	64	door jamb
630 kc	117	86	door jamb
1.5 Mc	126	88	corner-wall seam
5 Mc	128	100	door jamb
15 Mc	128	98	floor-wall seam
78 Mc	>120	113	door jamb
250 Mc	96	*	*
675 Mc	82	70	floor seam
1300 Mc	78	*	*
2800 Mc	73	57	wall seam
3400 Mc	58	53	door jamb

*No appreciable sources of leakage could be found.

In Table 3 the attenuation values as measured near the various openings in the double-shielded room are listed for comparison with the values obtained at the center of the room. Figure 10 shows the location of the openings referred to in Table 3. As very few measurements were taken near the air intake opening, attenuation values for the latter location were not included in the table. It is interesting to note that at some of the higher frequencies where standing waves were observed in the room, the attenuation measured near some of the openings was higher than in the center of the room.

It was suspected that if ordinary bronze fly screen had been used over the openings in the double-shielded room, in place of the hardware cloth, the over-all shielding effectiveness of the room would have been better. The hardware cloth in the door opening (about 8 x 10 inches) was replaced with bronze screening to test this contention and the leakage as measured in the center of the room again was determined at three frequencies. Table 4 summarizes the results and indicates that the fly screen is superior, at least for the frequencies used.

In the ultra-high and microwave frequency ranges, a standing-wave pattern was observed inside the room. The different maxima and minima showed little change in magnitude except at a few places along the walls where leakage was apparently occurring. The maximum values of field strength were used in all cases in determining the attenuation values for the rooms.

TABLE 3
Measured Attenuation at Selected Locations in Double-Shielded Room

Frequency	Attenuation at Various Locations in Room (db)			
	Center of Room	Near Opening in Door	Near Fan Opening	Near Light Wells
18 kc	70	56	51	46
88 kc	90	72	77	71
122 kc	100	77	75	69
630 kc	118	107	--	114
1.5 Mc	120	104	--	--
5 Mc	124	114	>126	112
15 Mc	120	106	--	104
78 Mc	>122	--	--	--
250 Mc	105	97	84	94
675 Mc	84	73	84	--
955 Mc	85	77	87	--
1300 Mc	69	65	73	--
2800 Mc	45	--	--	--

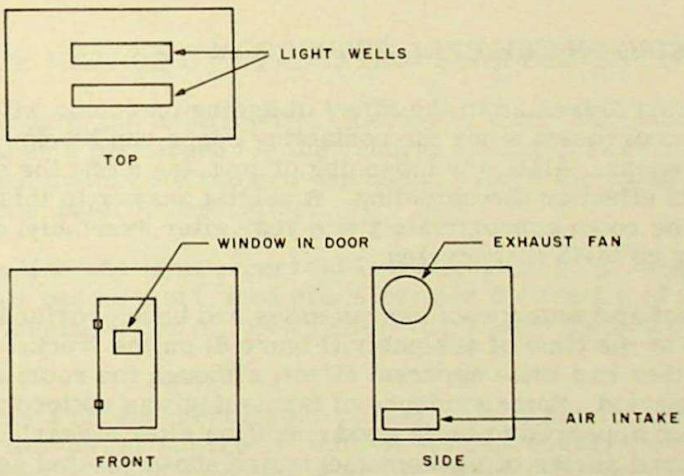

Figure 10 - Location of the mesh-covered openings in the double-shielded room

TABLE 4
Comparison of Hardware Cloth with Bronze Fly Screen in Door Opening

Frequency	Improvement in Attenuation Realized by the Use of Bronze Screening (db)
18 kc	8
1.5 Mc	16
15 Mc	26

The results of the tests show that there is very little difference in shielding efficiency between the two rooms measured. From theoretical considerations it would be expected that a double-shielded room would show greater values of attenuation than a cell-type enclosure. The main weakness of the double-shielded room was believed to be the hardware cloth used for covering the ventilation and light-well openings. Except for the lowest frequencies, penetration through the walls of the room was negligible, and the door seams were also found to be free of any appreciable leakage. It is believed that a double-shielded room of the type used in these tests is capable of much better performance than the test results indicate, provided that the hardware cloth is replaced with bronze fly screen. Using waveguide type openings for ventilation is a possible method for increasing the overall shielding efficiency.

The efficiency of the cell-type room used for the tests is considered to be good for this type of construction and exceeded the manufacturer's claims over most of the frequency range. One of the chief sources of leakage was found to be at one of the corners of the door. This leakage was apparently caused by the overlapping of two of the serrated Phosphor-bronze contact strips, which prevented uniform contact at this point. Other points of leakage were detected along the various wall and floor joints, although very few of these were individually large enough to influence the readings obtained at the center of the room.

EFFECT OF AGEING ON THE CELL-TYPE ROOM

A question often arises as to the effect of ageing on rooms without soldered seams. Any tarnishing or corrosion along the contacting edges can be expected to reduce the shielding effectiveness. Also, any loosening or warping along the seams would most likely have a deleterious effect on the shielding. A partial answer to this question was obtained by remeasuring the room approximately one year after assembly, at the same frequencies as used originally up to 15 megacycles.

A plywood roof and waterproof canvas sides had been provided to protect the room from the weather at the time of assembly (Figure 8) on the truck. Because of these precautions, the weather had little apparent effect, although the room remained outside during the whole period. Some evidence of tarnishing was noticed around the door, but otherwise the room appeared to be in good condition after a year's time. The attenuation values for the second series of measurements are shown plotted against frequency in Figure 11 together with the curve showing the original values. A definite reduction in shielding effectiveness is indicated. Extremely high values of leakage noted near several seams were thought to result from a loosening of the bolts that held the sections together.

For a final check, the room was returned to one of the medium-frequency test sites (WTOP - 1500 kc), and readings of field intensity were taken inside the room. The bolts throughout the room were then tightened and the field intensity again measured. The attenuation was now considerably higher, almost but not quite back to the original values. Leakage along the seams had in most cases been greatly reduced by tightening the bolts. Although the test was made at only one frequency, it is reasonable to assume that the effectiveness had been increased, at least to some extent, on all frequencies.

The vibration and shaking of the room, as a result of being mounted and transported on the truck, undoubtedly was responsible for the bolts loosening to such an extent, and, of course, would represent conditions much more severe than the room would normally experience in usual applications. However, temperature and humidity changes can be expected to result in some loosening even at fixed locations, because of expansion and shrinkage of the wood members.

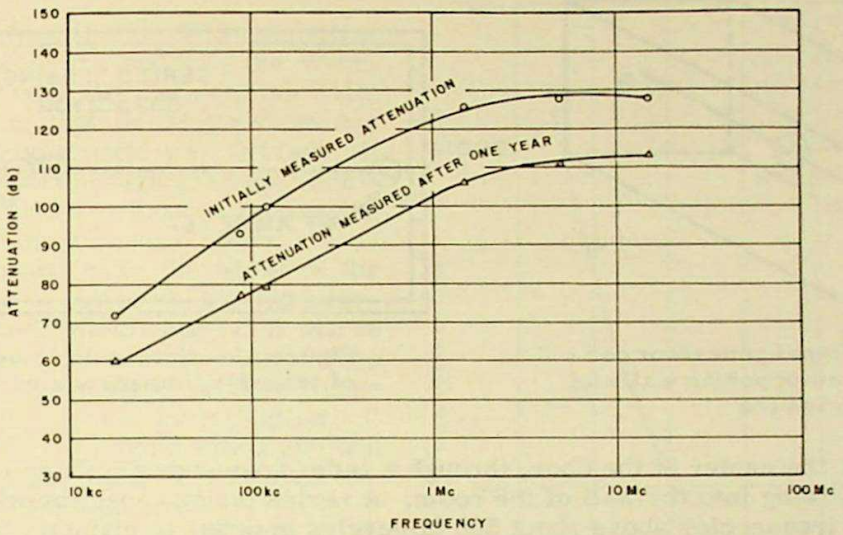

Figure 11 - The effect of ageing on the attenuation of the ACE cell-type room

TRANSFER-IMPEDANCE METHOD OF EVALUATING SHIELDED ENCLOSURES

As mentioned previously, the uniform-field method is much too elaborate and time-consuming to be adopted as a procedure for the general testing of screened rooms. However, the results obtained by this method provide useful values for comparison with those obtained by other methods under investigation.

A simple method, which was first suggested in a Report of NRL Progress (10), shows considerable promise for use as a standard procedure for the testing of screened rooms to specifications. It is an adaptation of the transfer-impedance method of testing coaxial cables (1).

Figure 12 represents a shielded enclosure composed of a single layer of conducting material. A relatively low-power source of radio-frequency energy is connected to the centers of two opposing walls, such as points A and B, causing current to flow between these points in the shielding material. For a perfect shield, the current would flow only on the inside surface of the enclosure; for imperfect shields, current will penetrate the material, decreasing exponentially from the inner to the outer surface. The amount of current flowing on the outer surface of a given material is inversely proportional to the square root of the frequency. Radio-frequency currents flowing on the outer surface of the conducting material set up electromagnetic waves which, if of sufficient strength, can be measured with conventional field intensity meters. In addition to the penetration loss, leakage also takes place at any discontinuities in the shielding, such as at wall or door seams and at ventilation openings, which allow currents to reach the outer surface. The intensity of the electromagnetic fields set up by these currents flowing on the exterior surfaces is an indication of the shielding effectiveness of the enclosure. The procedure used for setting up the equipment and conducting the investigations will be described with reference to Figure 13.

A signal generator (or oscillator) having a current output capability of at least one ampere at the various frequencies to be used (e.g., Rollin Model 20) is placed near the inside wall of the room, opposite the door. A terminal is soldered near the center of this wall and another at the center of the door. The ground side of the signal generator is connected by a short lead to terminal B, and the "high" side of the generator is connected to

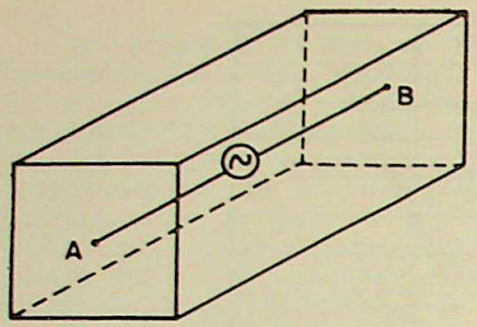

Figure 12 - Signal generator connected between opposite walls of a shielded enclosure

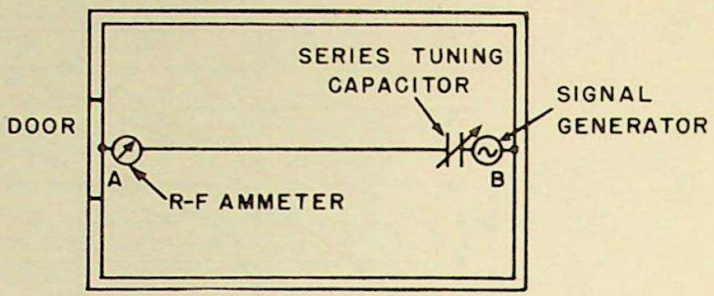

Figure 13 - Schematic diagram of transfer-impedance method

terminal A at the center of the door, through a radio-frequency ammeter for measuring the current flowing into the wall of the room. A series tuning capacitor was found to be necessary at frequencies above about 500 kilocycles in order to maintain the same current as at lower frequencies. The capacitor is placed in series with the line near the "high" side of the generator. The line between the generator and the center of the door should extend directly to the center of the door and be reasonably taut for best results.

With a fixed value of current in the line (e.g., one ampere), the field intensity is measured with loop-type equipment outside the room at various places around, and at various distances from, the outside walls. The maximum values will usually be found opposite doors, seals, ventilation openings, and other points where leakage is expected. The value of field intensity measured at a specified distance from the room divided by the current in the line is referred to as the "transfer impedance." It should be independent of the value of the current, but will depend on the position chosen for the field intensity measurements outside the room. The current should be specified in order to assure that large enough values will be used to provide a test for good rooms. Figure 14 shows a plot of field intensity at a fixed point versus current into the door.

The center of the door was chosen as the point for connecting the line to the inside wall for two reasons; first, in a good room the door is usually one of the major sources of leakage; second, it provides an easily specified point for standardization of test procedure. The optimum distance from the walls for measuring the field intensity appeared to be about six feet. Farther away, the signal strength tends to become too weak, closer, the gradient is too high. Figure 15 shows how the field intensity varies with the distance from the door. The best of the rooms tested gave measurable intensities at a distance of six feet. However, for extremely good rooms, it may be desirable to specify measurements at points closer to the room. Probing near the walls may be desirable for locating sources of leakage.

One possible source of error which should be investigated more thoroughly is

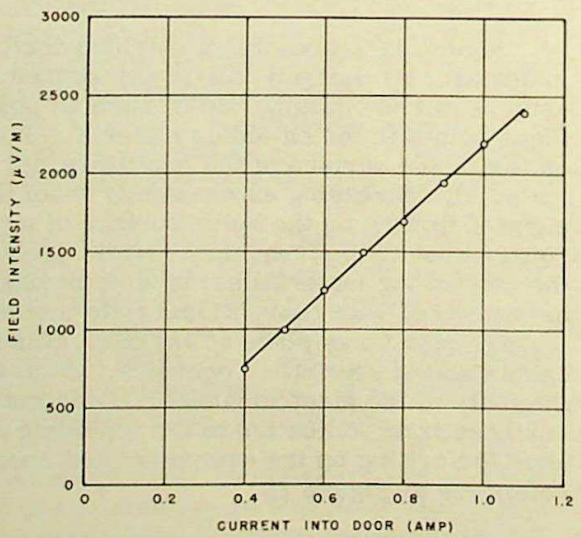

Figure 14 - A curve illustrating the proportionality between the current flowing at the door terminal and the external field intensity

the effect of the loop size on field intensities measured close to the walls of the room. The gradient is naturally high near the walls and is similar to that existing around any source of electromagnetic radiation. It should be noted that the high gradient condition is common to all methods of measuring shielded room effectiveness where measurements are made near the walls of the room. It is not peculiar to the transfer-impedance method. Whether or not it will be desirable to specify a certain size of loop as part of the standardized procedure can be determined after further investigation. It appears that values obtained with a 30-inch loop should, and do, differ from values obtained with a 6-inch loop.

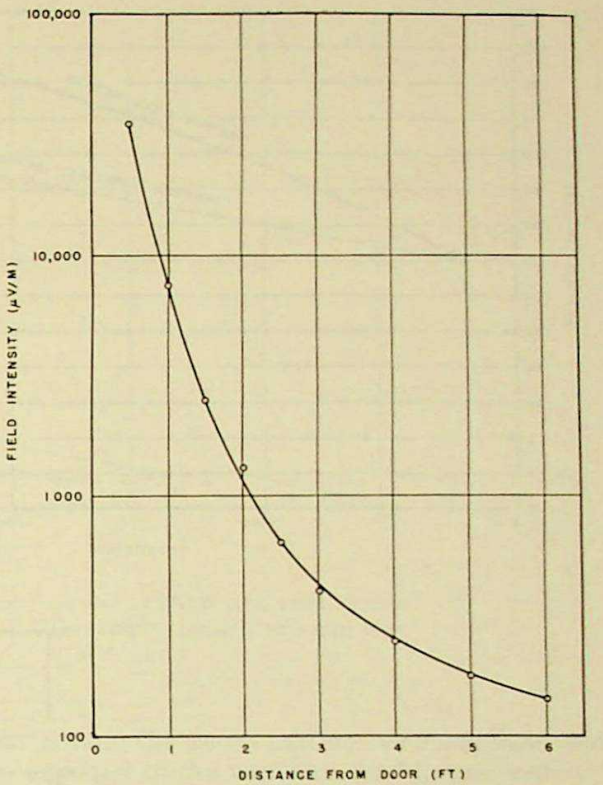

Figure 15 - Gradient of field in the vicinity of the door of the ACE cell-type room

For screened rooms being used to shield against radio waves in space, the first reflection is usually a significant factor in the over-all attenuation offered to the waves. The transfer-impedance method does not directly take into consideration this first reflection, since the initial source is the current flowing on the first surface. Measurements to date have indicated, however, that the results obtained are related to the over-all attenuation in a rather direct manner, but the relationship will vary somewhat with the method of excitation used for the regular attenuation tests, the results of which are to be used for comparison. In any event, the transfer-impedance method appears to give a significant answer. Although six different rooms have been used in the experimental work on this method, most of the tests were performed on the ACE room.

Comparison with the Uniform-Field Method

A series of measurements were made, as described above, on the ACE cell-type room at frequencies from 16 kilocycles to two megacycles. Figure 16 shows the inverse of the transfer-impedance values plotted in decibels (above an arbitrarily chosen reference value at 16 kilocycles) for comparison with the attenuation of the same room measured by the uniform-field method.

A single-shielded demountable room, manufactured by the ACE Engineering and Machine Company, was also utilized in the investigation. Because of the relatively lower attenuation to be expected in comparison with that of a cell-type room, it was thought that the attenuation curve could be obtained up to higher frequencies. The equipment was set up inside the room exactly the same as for the tests on the cell-type room, and the measurements made in the same manner.

A rough check of the attenuation of the room at 18 kilocycles was made by using the transmissions from NSS (Annapolis, Md.). This value was used as the reference point for the transfer-impedance measurements by plotting the inverse transfer-impedance values in decibels above the value at 18 kilocycles. The frequency range covered was 16 kilocycles to 24 megacycles. The curve is given in Figure 17 and shows that the attenuation increases uniformly up to about one megacycle after which it goes through several peaks

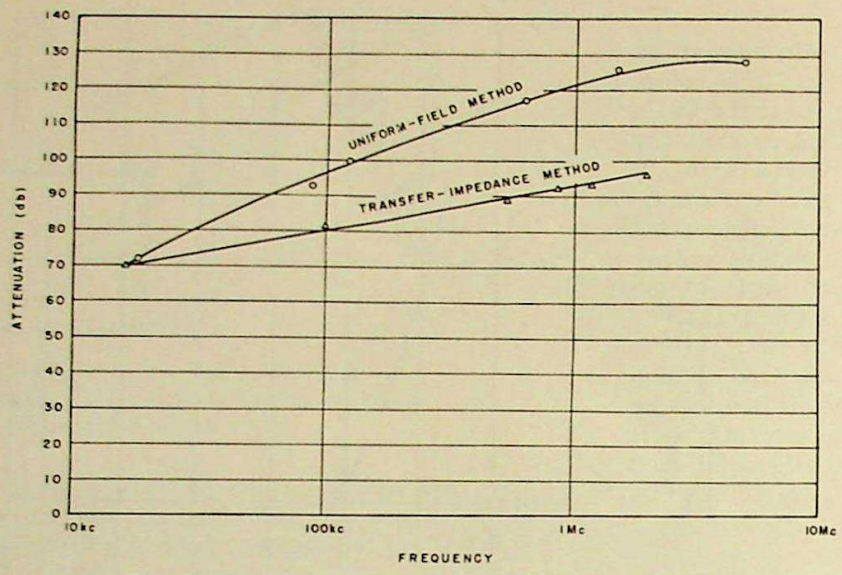

Figure 16 - Attenuation curves for the ACE cell-type room

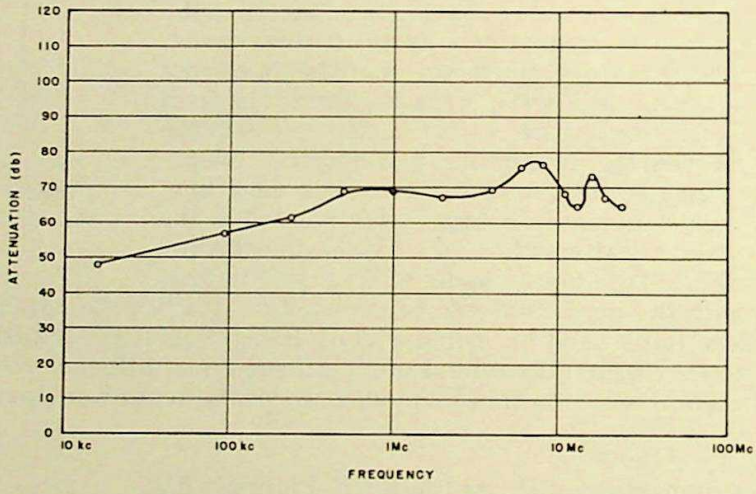

Figure 17 - Attenuation curve obtained by the transfer-impedance method on the ACE single-shielded room

and dips on up to 24 megacycles. The explanation for this behavior has not been definitely established, but probably involves resonance effects in the room or in the line used in introducing the current into the walls of the room. The upper frequency limit for measurements by this method is determined, in part, by the dimensions of the room. In all of the rooms investigated, it was found that above a certain frequency, usually between 10 and 20 megacycles, the current which could be fed into the room (as measured at the door) decreased very rapidly. Various schemes were tried, without much success, in an attempt to extend the frequency range beyond these limits.

A comparison of transfer-impedance values, obtained by the transfer-impedance method, for the ACE sirgle-shielded and cell-type rooms is plotted in Figure 18. In comparing the results it is noted that the single-shielded room appears to be slightly better than the cell-type room, assuming that shielding effectiveness varies inversely with transfer-impedance. The reason for this is probably due to the different conditions under which the two rooms were measured. The data for the single-shielded room were taken the day following assembly, while the cell-type room had been assembled about a year at the time of measurement, and had suffered a reduction in effectiveness (Figure 11). Although it would have been informative to have remeasured the cell-type room by the transfer-impedance method after the bolts had been retightened, this was not done, because the

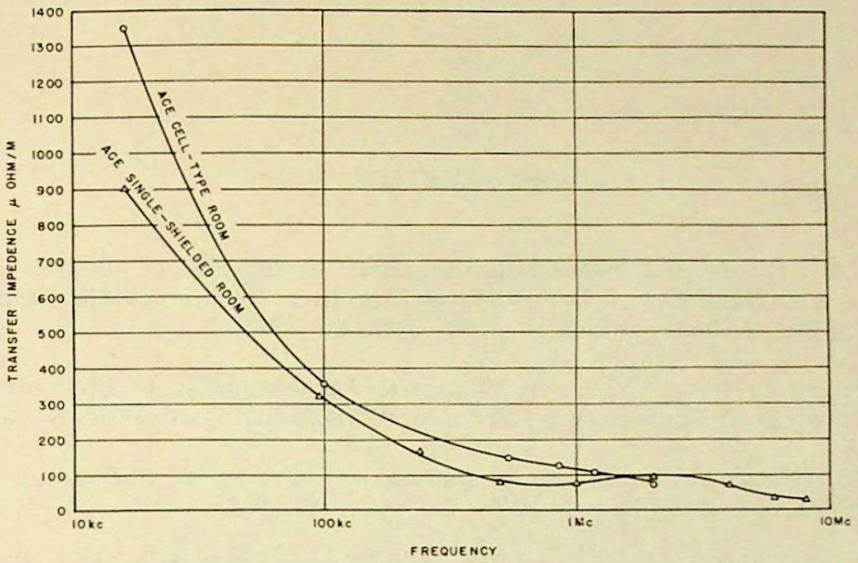

Figure 18 - Transfer-impedance curves taken six feet from the center of the door on the ACE single-shielded and the cell-type rooms

protective covering which had been constructed around the room had been removed in order to tighten the bolts. The room was, therefore, exposed to the weather, and to prevent possible damage from rain, it was disassembled immediately following the field tests.

One question which had been raised during these investigations was whether direct radiation from the oscillator was, in any manner, affecting the field intensity measurements outside of the room. A small oscillator on which the shielding could easily be removed was used to investigate this condition. With one ampere flowing at the door and the pickup device in a fixed location, measurements were made at several frequencies under two conditions; first, with the oscillator operating normally with all its shielding in place; second, with the oscillator shields completely removed. The difference between the external field intensities under the two conditions was not large enough to be measured, and it was therefore concluded that the degree to which the oscillator was shielded was unimportant for this application.

Advantages and Disadvantages

The advantages of the transfer-impedance method are:

1. Relatively low-power oscillators can be used in place of more powerful transmitter-antenna combinations.
2. The sensitivity is adequate for evaluating well-shielded rooms (within the upper frequency limitation discussed above).
3. Measurements are easily standardized and specified.
4. There are no interfering signals produced at distances remote from the room.

The disadvantages are:

1. The method is not readily adaptable to vhf and higher frequencies.*
2. The results are not directly obtainable in decibels of attenuation.

* There is no satisfactory method for use on the higher frequencies at the present time.

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